

## Information integration in the maritime domain

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In the maritime domain, the design of information for ship navigation tells us a story of information integration. As voyages became longer, knowledge about geography and fairways developed. What first could be harboured in the mind of a single person soon became written sailing directions, and later diagrammatic nautical charts. Today, navigators can rely on advanced static geographic information as well as dynamic information about the ship's position, other ships' positions, and the weather. For centuries, the problem was lack of information; today the problem risks being information overload. Our ways of designing information for navigation have changed, but the same limited human brain is still on the receiving end. This chapter uses the maritime world as an example of how information design has integrated enormous amounts of information into artefacts that allow users easy access to the right information at the right time.



**Figure 1** Knowledge in the head and knowledge in the world.  
a. A ship's bridge 100 years ago (RMS *Oceanic*).  
Harland & Wolff Collection, Ulster Folk & Transport Museum, HOYFM.HW.H297.  
© National Museums Northern Ireland.  
b. A ship's bridge today (mv *Kong Harald*).

There is one hundred years between the two pictures shown in Figure 1. The contrast is striking. On the left is the bridge of the *Oceanic* (a sister to *Titanic*); the photograph was taken some time before *Oceanic* grounded and sank in 1914. We can see the engine telegraphs and the compass binnacle; the ship's steering wheel was in the wheelhouse behind the two officers. Behind that was the chart room, where there were navigational charts; a sextant, chronometer, and barometer; and astronomical and tidal tables. On the right we see the bridge of a modern ship, one of the Hurtigruten RoRo passenger ferries that cruise along the Norwegian coast today. We can see the integrated bridge system with numerous instruments, screens, and gauges that supply the bridge officer with information.

One hundred years ago, the instrumentation needed to navigate an ocean-going vessel could be carried in a mariner's bag. The instruments

were few and the amount of data accessible to the bridge crew was very limited. Knowledge was mostly carried in the head as experience and rules of thumb. Navigational aids were few; the seafarer was everything. The fate of the *Oceanic* serves as an example: shortly after being commissioned into the Royal Navy in 1914, she ran aground and sank on a reef west of Shetland, following an inaccurate position fix during the night.

Today the situation is different. The number of instruments on a modern ocean-going vessel amounts to several hundreds. On the bridge alone a couple of dozen displays are monitored by the officer of the watch. The amount of data available is enormous, and there is no need to be in doubt about position, the whereabouts of rocks and shoals, the prevailing weather, the weather for the coming days, the wind and the current, the best course to avoid storms, and the position of other ships in the darkest night or the heaviest fog. No longer can the officer of the watch carry all available instruments in a bag; neither can he keep all his knowledge in his head. Much of his knowledge is instead placed ‘in the world’ (cf. Norman 1993). The problem for the officer of the watch is to integrate the available data to form a coherent picture of the world. But there is a limit to the integration work that a human can cope with. So integration must be done beforehand, to present the mariner with the right information at the right time. This is easier said than done. This chapter will look at how this integration has been done in the context of maritime navigation throughout history.

### **Information design on ships yesterday**

The past was dominated by scarcity of information, of not knowing where you were, of not knowing if you would arrive at your intended destination, of not knowing what the world as a whole looked like. The great achievement of the past was the mapping of the world.

#### **Reading-maps**

Although navigation is as old as mankind, no documentary evidence has survived of how it was done in early history. Although we have pictures on seal engravings of large ships driven by sail and oar, from Crete in the second millennium BC (Taylor 1956, 1), documents about navigation appear relatively recently in history. It is also likely that the art of navigation was a well-kept secret within the mariners’ guild (Cotter 1980, 7).

In the Scandinavian countries, the art of wayfinding at sea reached a peak by the end of the first millennium AD. The Vikings in their longships voyaged east to Russia and the Black Sea, along the western shores of Europe into the Mediterranean – and even further, to Iceland, Greenland, and Newfoundland. *Landnámabók*, an eleventh-century Icelandic manuscript (probably of much earlier origin), offers a description of the sailing route from Norway to Greenland:

From Hernam (near Bergen) in Norway you must hold on to a due western course, and that will take you to Hvarf in Greenland. On your way you will come so close to the Shetland Islands that you can just see them in clear weather. And you will sail so far from the Faroe Islands that you will see half of the hills in the water. And you will be so close to Iceland that you will see whales and birds from there. (Pettersen 1993)

This sailing direction is good enough to take a navigator from Norway to Iceland even today, and short enough to be memorized by one person. Climatology findings imply that the weather was warmer and more stable during the turn of the first millennium. The Vikings would not have to face the harsh North Atlantic climate as we know it today. Nevertheless, it was a vast undertaking to navigate the 1400 nautical mile long journey from Norway to Greenland. The directions of the wind rose were already named by the Vikings (*norðr*, *vestr*, *austr*, *sudr*). To find the right course at that time, before the knowledge of the magnetic compass had reached Nordic areas, the Vikings might have used a 'sun compass'. The only archaeological evidence is a piece of a wooden disk found in southern Greenland in 1948 (see Figure 2). The finding was interpreted thirty years later as a sun compass (Vebæk and Thirslund 1992). The simple instrument was a wooden plate with a wooden needle sticking up from its centre. Along the sides of the disk were marks like the direction marks on the compass rose. On the top of the disk were cuttings forming a hyperbolic curve. This curve could be interpreted as the curve described by the tip of the shadow from the needle during a four-week period around midsummer at latitude 62° N, providing the disk were horizontal and kept oriented in a steady position. Alternatively, it could also be used to find directions: by keeping the disk horizontal and turning it so that the tip of the shadow from the needle touched the line, courses within a few degrees could be held on the same latitude during the same time period of year.

The sun compass could be the device the Vikings used when the sky was clear. In cloudy weather the direction of the underlying swell that is ever-present on the ocean could have been used as a reference. A skilled mariner could read many helpful signs from the 'book of nature': the direction of a steady wind, the coming and going of birds on their way between their home cliffs and their fishing grounds, and the smell from land (Haasum 1974, 96). There is no evidence that the Vikings ever used the mythical sun-stone, a crystal which could polarize the light and thus show the direction of the sun on overcast days (Roslund and Beckman 1994).

But knowing which direction to sail is one thing. Not only would the compass not be very precise, but neither would the steering of a longship. The effect of currents and wind over long distances could be considerable. These factors could add up to a large error if the navigator had no way of establishing his position. The Vikings crossing the North Atlantic used a method known as latitude sailing – based on the fact that the height



**Figure 2**  
A Viking 'sun compass', a wooden fragment found in Greenland in 1948. National Museum, Copenhagen. Photograph: Lennart Larsen. CC-BY-SA.

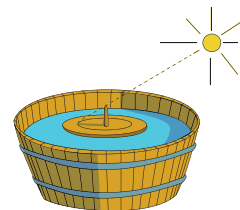
of the sun at midday would always be the same as long as they were on the same latitude. To keep track of the height of the sun they used a *solskuggeffjøl*, a ‘sun-shadow-board’. This was a device much similar to the sun compass, and the two functions could easily have been integrated into one instrument. Like the sun compass, the *solskuggeffjøl* was a wooden disk with a wooden needle sticking up from its centre. However, the disk rested in a barrel of water to ensure that it was horizontal (see Figure 3).

Along the rim of the disk one or more concentric circles were cut, each representing a different latitude or a different time of the year. Viking voyages were undertaken in a short period in the middle of the summer and along the 61st or 62nd parallel, so that only one circle would be needed. The reading was done at midday, and if the needle’s shadow crossed the line, it meant that the sun was too low and that the ship had drifted too far north, requiring a correction. Later in history the sextant was used for the same purpose.

Apart from the sailing directions in *Landnámabók*, no written evidence for how the Vikings navigated has survived. Although some Vikings ventured over the open seas, most Nordic sea traffic in this period clung anxiously to the coasts. Weather and pirates were a constant threat to the traders. As long as boats were small, dangerous shallow shoals could be spotted by lookouts, and if a boat ran aground, the crew could climb overboard and lift it off. But bigger boats were needed that could take more cargo and house the crew on longer journeys. These bigger boats had deeper draughts, and it would not always be possible to spot deeper shoals. Nor could such boats easily be lifted off if grounded, and their relatively thinner planking could easily be damaged. The need for safer and better known routes increased.

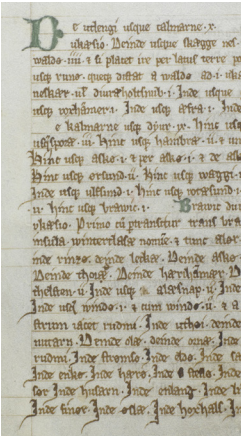
As long as early seafarers stayed near their home ports, the geographic knowledge necessary to find way could reside in one man’s memory. But when voyages became longer the question arose – how could knowledge of distant waters and coasts be communicated from locals to the maritime community? No doubt local pilots were of crucial importance, and trading trips required a constant stream of pilots boarding and leaving the ship. Pilots had to be paid, and one can imagine that they were not always available, so it is only natural that once a literate mariner turned up, he would make notes of his voyage – the places, the distances, and the landmarks. It is in this form, as a verbal narrative, later illustrated by simple drawings, that the first accumulated knowledge of wayfinding at sea has come down to us. We can call such an artefact a ‘reading-map’.

In the thirteenth century directions were written for a sailing route from the south-western corner of Sweden, up the east coast to Stockholm, and eastward through the archipelagos of Åland and south-eastern Finland, and south to what is now Riga in Lithuania. This document (named for the reigning Danish king) is written in Latin, but its Nordic origin is proved by the use of local names and local units of distance (Dahlgren and Richter



**Figure 3**  
The Vikings could have used a *solskuggeffjøl* (sun-shadow-board) to keep the latitude between Norway and Greenland.





**Figure 4**

a. Detail from  
*Kung Valdemars  
jordebok*.

The Danish National  
Archives, Copenhagen.



b. Map of the  
Swedish east  
coast today. The  
names in bold  
type correspond  
to the names  
in the sailing  
description.

1944, 10). The sailing direction (Figure 4) is simply a list of places and distances. It says nothing about which sounds are deep or where shoals are. No directions are mentioned, as this pre-dates the use of the compass in Nordic countries. Nevertheless, sailing directions were invaluable to foreign trading ships that could sail up the coast with the help of local pilots.

### The Mediterranean

Although mariners in the Mediterranean had sailed very much larger ships for thousands of years, archaeological evidence of nautical information is of relatively recent date. The first evidence of Mediterranean navigation survives in a document called a *periplus*.<sup>1</sup> The *periplus* of Scylax of Caryanda is a set of sailing directions for the Mediterranean and the Black Sea from the fifth century BC. Trading routes still hugged coasts, so *periplus* were accounts of ports and distances, of prominent landmarks, with occasional warnings for underwater shoals, and identifying places for taking on supplies, especially water. The following fragment is typical:

Libya begins beyond the Canopic mouth of Nile ... The first people of Libya are the Adymachidae. From Thonis the voyage to Pharos, a desert island (good harbourage but no drinking water) is 150 stadia. In Pharos are many harbours. But ships water at the Marian Mere, for it is drinkable. It is a short sail from Pharos to the mere. Here is also Chersonesus and harbour: the coasting thither is 20 stadia. Beyond Chersonesus is the bay of Plinthine. The mouth of the bay to Leuce Acte (white beach) is a day and a night's sail ... (Cotter 1971, 250)

*Periplus* and the later *portolanos* and *compassos* of the Italians and the *leeskaarten* of the Dutch renaissance all had the narrative in common. They were sequential descriptions of a voyage, verbal snapshots from specific points of the coast, as seen from the perspective of the ship's bridge. They were written to be used when sailing in one direction, and could not as easily be used for sailing in the opposite direction.

But some features along the route might not be so easy to describe verbally. A drawing could more easily show the shape of an island or a cliff. It would only be natural if these early mariners, once they had started to document their sailing routes, also started making drawings of the coast from the same egocentric perspective.

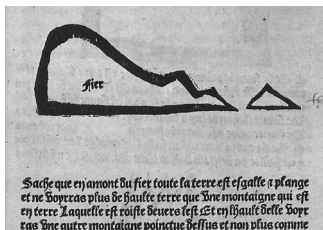
### Coastal views

A moment of utmost importance for the mariner, once he had left the coast and ventured out on to the open sea, is landfall on a new coast. Has he reached the shores he had been heading for? Will an open harbour await him – or unfriendly rocks? From Old Norse *landkenning*, the word kenning has been incorporated into the English language. A kenning is 'a unit of distance used by the early mariners, equivalent to the distance at

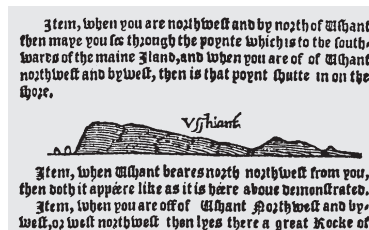
<sup>1</sup> The Greek word *periplus* means 'round voyage' or 'circumnavigation'.

which the shore could first be seen from the offing when making a landfall' (Cotter 1971, 260). It follows that the distance of a kenning was furthest off a mountainous coast. Once land had been sighted, the mariner quickly had to identify the location by whatever means he had, often just based on his recollection of earlier encounters, or the verbal descriptions from fellow mariners, or maybe a sailing direction. Not all destinations had as prominent and easily described a landmark as the tower on Faros outside the port of Alexandria, or the colossus of Rhodes. Thus a drawing of coastal features would have been of great help.

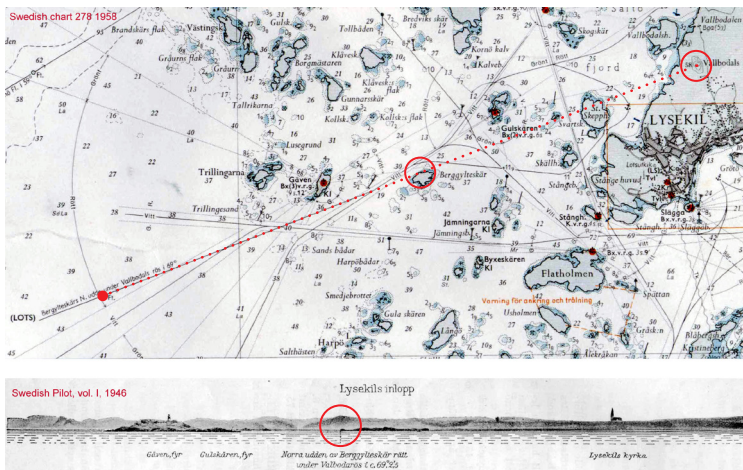
In 1483 the French pilot Pierre Garcie published *Le grant routtier et pyllotage* (Figure 5), its text was interspersed with woodcut illustrations of coastal views. Such illustrations were later developed and refined by the Dutch (see Figure 6). The perspective is 'from the bridge'. The shore profile depicted the coast from a specific point at sea and the silhouette of land was emphasized. It was crucial for the pre-GPS mariner to be able to establish his position by identifying landmarks. The same techniques are still used by pilots using drawings or photographs (see Figure 7).



**Figure 5**  
A coastal view of Cap Higer on the border between France and Spain in the Bay of Biscay. From Pierre Garcie's *Le grant routtier et pyllotage* (1483).



**Figure 6**  
A coastal view of Ushant at the tip of Brittany. From Robert Norman's *The safegarde of saylers* (1590), translated from the Dutch (Taylor 1956, 169).



**Figure 7**  
A chart of the approach to Lysekil and corresponding coastal view. 'Ft.' at the bottom left of the chart is the point of origin for the coastal view. The chart's diagonal fairway line (highlighted in red here) through 'Ft.' towards the port corresponds to the vertical stippled line on the coastal view; the tip of the island and the peak on the horizon provide points of reference.

The sailing direction was the major medium for communicating navigational information to the mariner until the end of the eighteenth century, when its function was overtaken by the chart (Hutchins 1995, 108). The reason is simple: the information communicated by sailing directions and coastal views was serial. By following a specific route, the landmarks and the views would follow in the order of the direction. But what if you wanted to travel the opposite way? Once large amounts of data had been acquired and the geographical layout of the seas became better known, new direct routes became an option, making sequential sailing directions less useful. A new integrative medium was needed and the nautical chart, or mariners' map, was the answer.

### Nautical charts

A map is a representation of the world around us. However, the view is not from our own egocentric perspective; instead, the world is depicted from above, from an artificial viewpoint. Although early cartographers might have had the opportunity to climb a high mountain, it was not until the eighteenth century, with the invention of the hot-air balloon, that humans could experience this bird's-eye perspective. And even a balloon pilot would only see the area directly underneath the balloon without perspective distortion, as the view would become more and more obliquely compressed and distorted towards the horizon. This is not how a map works. On a map every location is seen from straight above. While this artificial perspective cannot be experienced in real life, we do not seem to have a problem with it when reading a map. It seems that we have a built-in cognitive ability to imagine that we are looking down on ourselves from an elevated position. Most of us have at some point drawn a map after walking around a location, or just by recalling it. Something in the structure of the human mind seems to facilitate these dual perspectives of the world, the egocentric and the exocentric. Indeed, the earliest maps from Babylon, some 3,500 years old, use an isometric bird's-eye perspective and are already fully featured (Figure 8).



**Figure 8**

A clay tablet from Mesopotamia from the 16th century BC. The map depicts Nippur on the Mesopotamian river plain east of Babylon in present-day Iraq. A part of the city wall and a temple can be seen to the far right. A canal is represented by two parallel lines just right of centre, and to the far right is a branch of the River Tigris.

HS 197, Hilprecht Collection, University of Jena. Used with permission.

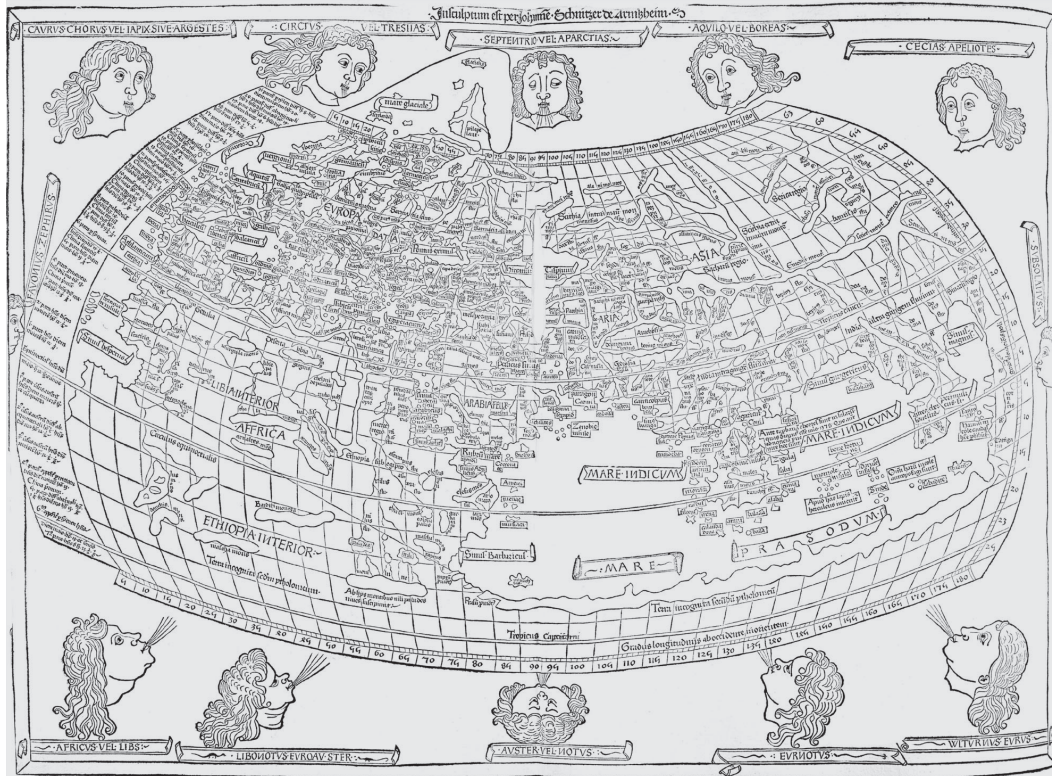
It is one thing to make a map of the world immediately around you, the world that you can easily see and measure. It is quite another thing to make a map that covers vast areas that cannot be seen from one position. In western culture it was the Greeks, as far as we know, who started to think about the form of the world. Homer considered the earth as being a flat disc surrounded by water. The sun rose from the ocean in the morning and sank back into it in the evening. However, in the sixth century BC Aristotle concluded that ‘the sphericity of the Earth is proven by our senses’ (Holmes 1991, 24). If you have ever sat by a harbour and watched a sailing ship approaching from the open sea, the first part of the ship to come into view would be the top sails, then the rest of the rigging, and finally the hull itself. This is as true today as it was 2000 years ago. If the ship was not being lifted up from the water, then the only explanation must be that the Earth is round. The Greeks also noted that the stars every night travelled their paths from east to west. But if you sailed south from Piraeus to Alexandria, new stars would rise in their paths over the southern horizon and the paths of the northern stars would sink towards the horizon. This could only be the case if the earth was round. Some astronomers also noted that the shadow of the earth while crossing the surface of the moon as she travelled into an eclipse was rounded, thus indicating that the shape of the Earth must be spherical.

The Greek mathematician Eratosthenes, who worked at the library in Alexandria in the third century BC, even managed to calculate the circumference of the earth. In a famous experiment his accuracy was such that the result was only 14% off the correct distance. Unfortunately, the man who was to become the father figure of cartography, Ptolemy, in the second century AD, used a calculation from the first century BC, by the geographer Strabo, when he compiled the geographic knowledge of his time. Strabo had calculated the circumference of the earth to 32,700 km and Eratosthenes to 45,500 km (the circumference is about 40,000 km). Eratosthenes’ measure was forgotten, while Ptolemy’s lived on. Ptolemy’s calculation would, more than a thousand years later, lead Columbus to believe he had reached India, when he had only reached the Caribbean.

Ptolemy compiled the knowledge of his time and made great additions to it. He was probably the first who systematically used longitude and latitude to describe positions on earth (see Figure 9). Realizing the problem of depicting the surface of a round sphere on a flat paper, he also did some basic work on the problem of projection.

Three hundred years after Ptolemy died, the library in Alexandria, where he had worked, had ceased to exist, and for a long time it was as if cartography had been forgotten. In the Christian Europe of the Middle Ages, the language of the scholars was Latin and few could read the surviving books of the Greek masters. Ptolemy’s *Geography* was not translated to Latin until 1406, but his ‘new’ knowledge of the world then spread across Europe. Ptolemy’s maps, revised by findings of the early explorers,





**Figure 9**

A late 15th century non-illuminated woodcut map, as a double-page spread in a Latin translation (*Cosmographia*) of Ptolemy's *Geography*. The orientation is north-up and a geocentric grid is presented. The longitudes start at 0° at the Canary Islands and end at 180° in China. (Ptolemaeus 1482).

remained the main source of geographic knowledge until the seventeenth century (Holmes 1991, 91).

During the Middle Ages cartography developed in different directions. The medieval monks were not interested in scientific cartography and their maps were not used for navigation. While the Church clung to their *mappae mundi* depicting a flat Earth centred on the Mediterranean and Jerusalem, mariners developed maps for their own practical purposes.

### Portolan charts

While makers of land maps depicted towns, roads, rivers, and mountains, mariners were interested in quite different things such as depths and coastlines. John Blake notes that the sea chart has to 'reflect varying information in a fluid situation' (2004, 8) – meaning that the chart had to be able to reflect the changing environment that the sailor would meet during different tidal situations, when the changing depth of water could affect the accessibility of fairways and harbours hour by hour.

The earliest nautical chart that has survived, the *Carta Pisana*, is from Pisa and dates from 1275 (Taylor 1956, 109; Figure 10, overleaf). It is a map of the whole of the Mediterranean Sea. Large amounts of information from the sequential sailing directions is integrated in a diagrammatic form that allows the reader to make inferences at a glance about distances





between locations. The coastlines are filled with names of ports, bays, and rivers. These features are colour coded, with red text for major ports and black text for minor, and sometimes the religious status of the port is also denoted. This kind of chart is called a portolan chart, named after *portolano*,<sup>2</sup> the Italian type of sailing direction which appeared at the end of the twelfth century after the compass was introduced in western navigation. In these new sailing directions, compass directions (bearings) for different destinations are set out, and the most characteristic trait of the portolan chart is the maze of intersecting lines covering the sea areas. Each is a rhumb line – a straight course (technically a loxodrome) that will take you from one point to another (Cotter 1971, 260).

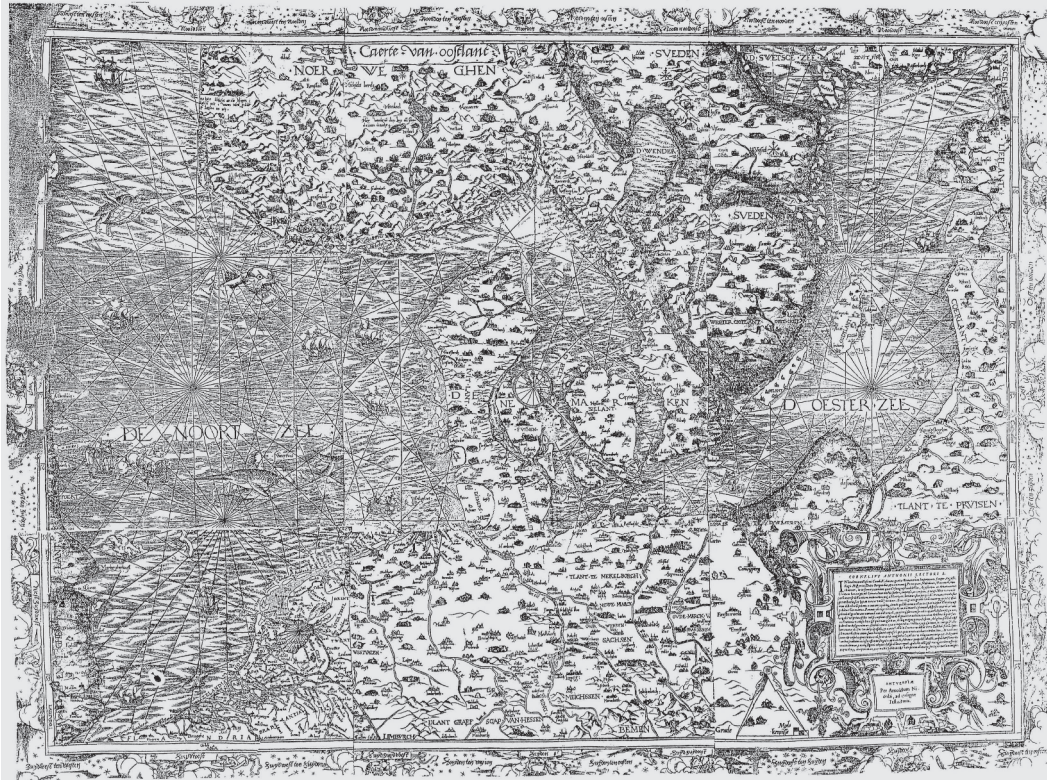
The portolan charts were expensive pieces of art, written and painted by hand on vellum, and often embellished with luminous colours. They were certainly not intended for the rough environment on board an ordinary trading ship. Simple, practical navigation was still done with the aid of sailing directions and pilots.

The Dutch were the next to take the lead in cartography. In 1543 Cornelis Anthoniszoon published the first real nautical chart of Scandinavian waters: *Caerte van Oostlant*. It was based on copperplate engraving as opposed to the earlier woodcut technique. The new technique made it possible to make much finer details (see Figure 11).

From an information design point of view Anthoniszoon's chart was a failure. Geographically, the chart was the best available, but in an ambition to include as much information as possible, the chart is cluttered to the point of obscurity. As an example, it is very difficult to distinguish the tiny dots depicting shallow water from the predominantly decorative wave texture.

2 The Italian word *portolano* means 'book of ports' (Dahlgren and Richter 1944, 4).

**Figure 10**  
Carta Pisana (1275), the first known nautical chart, was depicting the Mediterranean and drawn on a sheepskin. The intersecting rhumb lines of the wind-rose are constructed in a large circle.  
CPL GE B-1118 (RES).  
Bibliothèque nationale de France.



**Figure 11**  
The Dutch  
Cornelis  
Anthoniszoon's  
*Caerte van  
Oostlant*,  
published in 1543.  
From Dahlgren and  
Richter 1944.

The nautical chart made great advances during the Dutch era. In 1569 Gerard Mercator published his famous world atlas, and with it the map projection that carries his name. It allowed mariners to draw a straight line between two points on the chart, to measure its angle to the meridian on the chart, to compensate for magnetic variation and the ship's deviation, and then to sail that course on the compass. And, once current and leeway were taken into consideration, be confident of reaching the intended goal. This was indeed a great step forward. The Mercator projection became standard for most short- and medium-distance navigational charts.

The next important person in the development of the modern chart was the pilot and geographer Lucas Janszoon Waghenaer. From 1584 to 1585 he published an atlas, *Spiegel der Zeevaerdt* (translation into English as *The Mariner's Mirrour*), with nautical charts extending from Spain to the Baltic Sea (see Figure 12, overleaf).

Waghenaer's *Spiegel der Zeevaerdt* was something new. No one had previously tried to compile such an extensive amount of hydrographic information. The problem of clutter on Anthoniszoon's charts was elegantly solved by dividing a large area up in several smaller charts at different scales. Himself an experienced pilot, Waghenaer knew what he was doing. For the first time, depth soundings printed on a chart was standardized to mean water level. Many new map symbols were also introduced, some





**Figure 12**

Plate 38 in Waghenaeer's *Spiegel der Zeevaerdt*, 1585. The chart covers the bay of Danzig in the south-east Baltic Sea. Waghenaeer did not use the north-up convention, but instead rotated the map to fit the paper format in the most economical way. Utrecht University Library.



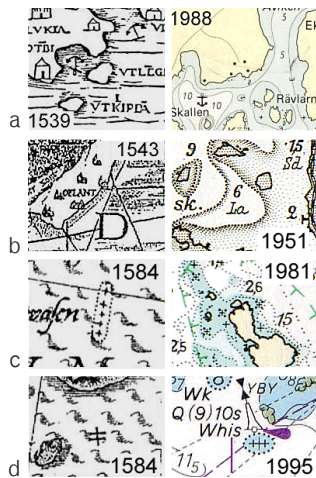
**Figure 13**

A section of the Swedish coast (Västerwik to Söderköping) in Waghenaeer's *Spiegel der Zeevaerdt*, 1585 (Plate 33). Note the coast profiles incorporated into the beach lines and the odd surface perspective of the central island. Symbols used are an anchor, a cross indicating underwater rocks, and a two-armed cross indicating a wreck. Utrecht University Library.

of which are still in use. Waghenauer also tried a new innovative approach when he mixed the bird's eye perspective of the chart with the surface perspective of the coastal view, by incorporating coastal views into the shorelines of the map (see Figure 13). This technique worked fine for flat coastlines, but became more troublesome the more inlets, peninsulas, and small islands the coast had. Waghenauer tried to overcome this problem by drawing some selected islands in perspective (see the island in the lower part of Figure 13).

Waghenauer's sea atlas became a success and was soon translated into several other languages. But he did not succeed in all respects: his atlas never became common onboard seagoing ships. The large, expensive, hand-coloured volume was unsuitable for the rugged environment at sea. Waghenauer realized this himself, and in 1592 he published *Thresoor der Zeewaerdt*, a traditional text-based sailing description in a smaller format, where he had added some coastal views and smaller versions of some of his charts.

Experimentation with different kinds of representation soon disappeared, and the chart eventually found its stable form as an orthographic bird's-eye perspective. New symbols evolved to improve communication. Examples of symbols that would remain in use up to the present day are the anchor to indicate a safe and protected anchorage, dot-textured areas to depict shallow water, the cross sign to mark a dangerous shoal, and the stylized keel and frames of a sunken ship to denote a dangerous wreck (see Figure 14).



**Figure 14**  
 Examples of chart symbols that have survived from the sixteenth century.  
 a. anchorage  
 b. shallow water  
 c. shoals  
 d. wreck

The Dutch were still the major chart makers during the first part of the seventeenth century. In fact it was the Dutch that charted the English coast. But in 1669, an Englishman, Johan Sellars, announced his intention to prepare a 'sea waggoner for the whole World'. The first volume of *The English pilot* was published in 1671. At first Sellars used discarded Dutch

plates for his charts, but in 1689 the fourth volume of *The English pilot* appeared as the first wholly English sea atlas of American waters (Cutter 1979, 10). Coastlines are depicted with a single solid line like on modern charts. The rhumb lines from the portolan charts are still there, but the grid of longitude and latitude that we know today is also present. The modern chart was born, becoming the major navigational aid for the mariner, and sailing directions gradually lost their importance (see Figures 15 and 16).

### **A summary of yesterday's information design on ships**

Two perspectives have been present in this overview of the development of mediated communication at sea: The 'bridge' perspective of the sailing direction with its sequential narrative of a ship's journey, and the static bird's-eye perspective of the chart. The two perspectives represent two different methods for communicating geographic information to the mariner. In the first case, the perspective is that of a static observer, with the surrounding world passing by. In the other case, the perspective is that of a third person: the world is static and we imagine ourselves as an observer travelling over the representation with a bird's-eye view. Both of these perspectives have their advantages and disadvantages.

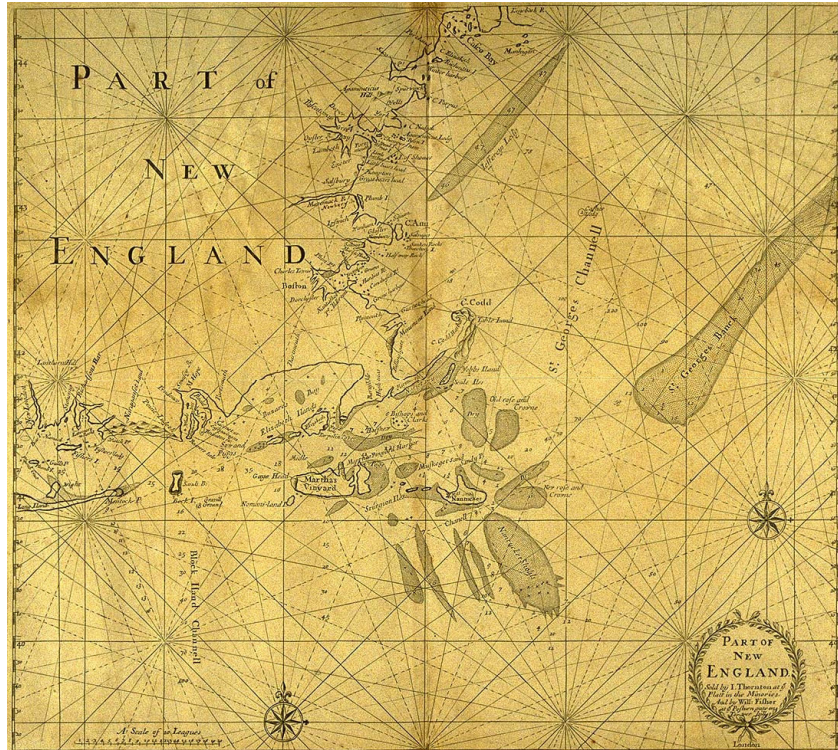
The coastal views of the sailing directions are very good at communicating the actual look of the coast to facilitate our orientation and decision-making. But note that this is only the case for one specific position, the one from which a picture is drawn or a photo taken. Only a slight change in position might make the coastal view unrecognizable. Also, topographic features, which most often are omitted from charts, give the mariner valuable information. The most obvious advantage of the coastal view is the 'natural' perspective, facilitating mariners' intuitive decision-making – as opposed to the synthetic perspective of the chart, which has to be learned. The biggest problem is the static nature of the sailing directions' coastal views.

The chart is superior when it comes to planning the voyage and monitoring progress. Geographic positions are easy to plot, and the chart can be described as working like an 'analogue computer' (Hutchins 1995, 61). Used in the conventional north-up mode, the chart facilitates our sense of direction ('I am going south'). Used in a head-up mode (for example turning the map upside-down when going south) the sense of relative direction is enhanced (a left turn on the map is a left turn in reality), but the sense of absolute direction is hampered. And a nautical chart is also a wonderful container of geographic knowledge. A single chart can 'represent the accumulation of more observations than any one person could make in a lifetime. It is an artefact that embodies generations of experience and measurements' (Hutchins 1995, 111).

Information needed for one single voyage could indeed be kept in the head of one man, but to harbour information for a large number of voyages the sequential narrative of the sailing directions was needed.

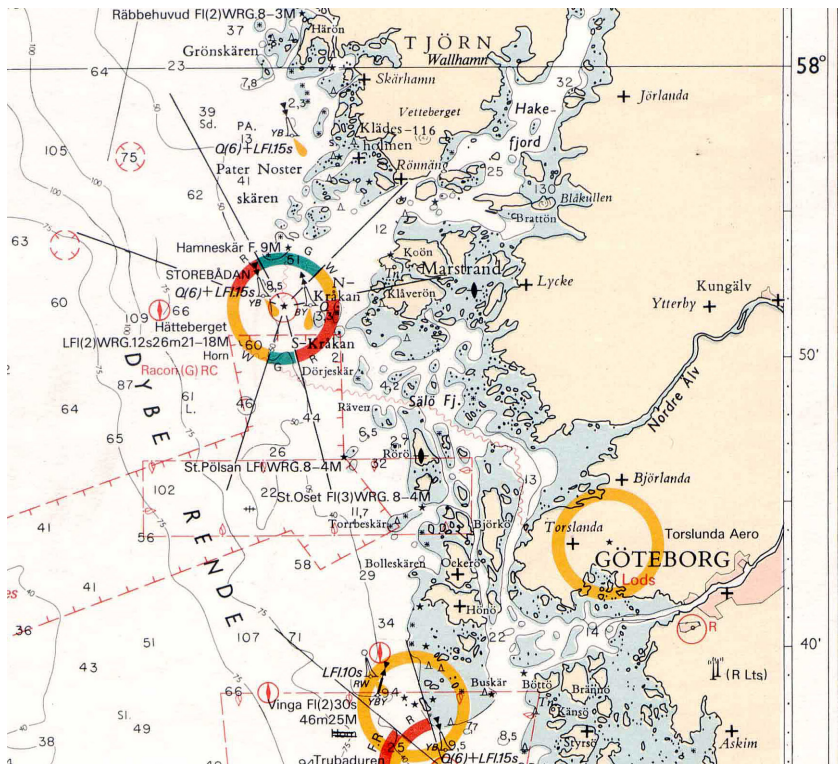


**Figure 15**  
The New England chart from the fourth volume of *The English pilot*, 1689, engraved by John Thornton. His chart was the first chart depicting American waters, accurate enough for navigational use. It includes soundings as well as banks, shoals, islands, and coastal features.



**Figure 16**  
The modern paper chart at its height of cartographic development. Uncluttered and with only relevant information for its scale. This coastal chart is designed for sailing through the Kattegat or making landfall at Gothenburg (Göteborg) harbour.

The Danish Farvandsdirektoratet. Chart no. 92 from 1980, scale 1:360.000.



The knowledge of all those sailing directions was later integrated into the diagrammatic form of the nautical chart, allowing any number of voyages to be planned and executed. But possibly, it can be argued, at the cost of a less user-friendly medium.

### **Information design on the bridge today**

If the past was about the lack of information, the present is about an abundance of information. Today the problem is to digest and understand the mass of available information in a timely manner. The great challenge of the present is to generate and provide all this information.

#### **Positioning**

The problem of the ancient navigator was lack of information. Sailing by latitude – by keeping track of the height of the sun or the stars – was improved by the development of better instruments: the cross-staff, the octant, and finally the sextant. However, perfecting the instruments did not solve the problems of rolling decks, of a horizon obscured by haze or waves, or the fact that the sun or the stars could be hidden by clouds for long intervals. No azimuth reading meant no latitude.

Finding longitude remained a problem up until the 1730s, when John Harrison succeeded in making a chronometer that could keep time on a rolling ship with sufficient precision to allow the time of a reference longitude to be transported across the ocean. By comparing the time when the sun was at its peak, noon at the ship's longitude, to the reference time of the chronometer allowed the navigator to calculate the current longitude.

The advent of practical radio communication with Marconi's first transatlantic radio transmission in 1901 allowed a new positioning method, based on measuring the runtime of electromagnetic waves, significant after Einstein postulated, in 1905, that the speed of such waves was constant. This eventually led to the development of radar, the Decca and LORAN navigation systems, and, from the 1980s, satellite-based positioning systems.

Having longitude and latitude shown on a little display – instead of doing the cumbersome calculations based on sun height and a stopwatch – was a great achievement. At first the number of satellites was limited, and the position calculated could at times be inaccurate. Today, with global navigation satellite systems like the American GPS, the Russian GLONASS, the Chinese BeiDou, the European Galileo, and Indian and Japanese systems under development, fixing a position is less of a problem.

#### **The electronic chart**

But why should you have the position spelled out as numbers on a small display, when what you really want to know is your current position on a chart? The answer to this question has been the development of Electronic

**Figure 17**

An electronic chart is a vectorized, seamless geographic information system where layers can be shown or hidden as necessary. The figure shows an electronic chart in a Swedish Adveto ECDIS-certified system. The ship (black-filled symbol) is in the central upper part of the screen heading on a ssw course. The system is predicting the ship's position 30 seconds into the future (black unfilled symbol). The red line is the course as programmed from waypoint to waypoint.

Courtesy Adveto AB.

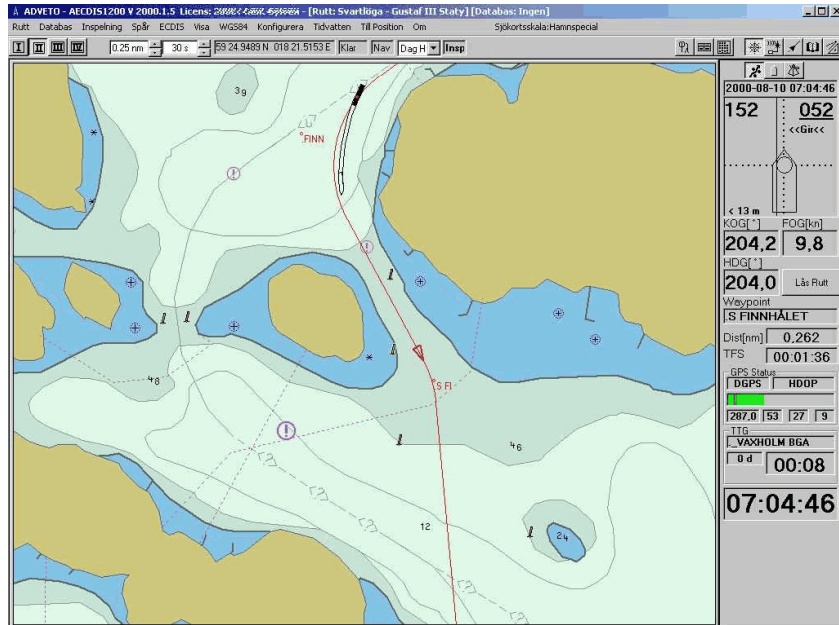


Chart Display and Information Systems (ECDIS). Together with a satellite positioning system, this allows the officer of the watch to see the ship's position plotted on a map and allow the ship to automatically follow a pre-planned course between two ports (see Figure 17).

Experiments with electronic chart systems started in the late 1970s (see for example CAORF Research Staff 1978; and Rogoff and Winkler 1980). This became the ultimate tool for integration and display of maritime information. In 1989 the International Maritime Organization issued the first provisional performance standards for ECDIS (IMO 1989). In 1995 the US Coast Guard Research and Development Centre presented a human factors study of two commercial ECDIS on a simulator bridge. One of the principal findings was:

ECDIS has the potential to *improve the safety of navigation*, compared to conventional procedures. There was strong evidence that the use of ECDIS increased the accuracy of navigation, as measured by a smaller crosstrack distance of the ship from the planned track line, and reduced the proportion of time spent on navigation, with a corresponding increase in the proportion of time spent on the higher risk collision avoidance task. In addition, ECDIS was shown to improve geographic 'situational awareness' and to reduce navigation 'errors'. (Smith et al. 1995, viii)

The study also found that the availability of ECDIS on the bridge substantially reduced the mariners' workload as a result of less time spent on navigation. A year later the US Coast Guard presented another study, this time including both sea and simulator trials. The conclusion from that study was that ECDIS could provide equivalent or greater safety than



the paper chart and other traditional methods of navigation. Another key finding was that navigation workload was reduced, allowing the mariner to concentrate on collision avoidance or other tasks of similar importance. With respect to user interface design, it was found that the mariner wanted an ‘uncluttered’ display during route monitoring, with more features immediately available if needed (Gonin, Dowd, and Alexander 1996, iii).

A number of simulator studies have since been carried out comparing the traditional bridge with modern forms of integrated bridge systems. Sauer et al. (2002) published an experimental navigation study comparing electronic charts and radar integrated in the same display with separate electronic charts and radar displays. The results indicated a slight advantage of the integrated display. A simulator study (Donderi et al. 2004) compared a traditional bridge set-up with paper charts and radar against electronic charts with separate radar and also against electronic charts with integrated radar overlay. In a navigational scenario the study found slightly better performance with the use of ECDIS, with participants preferring integrated radar overlay.

A Norwegian simulator study compared performance between ECDIS navigation and traditional paper chart navigation in high-speed navigation in very confined waters (Gould et al. 2009). ECDIS navigation was found to be more efficient, but with no significant differences in subjective workload. A similar study found only a small advantage for the integrated bridge with ECDIS and separate radar, as compared to paper chart and radar (Nilsson, Gärling, and Lützhöft 2009). In a doctoral thesis from 2004, Lützhöft presented empirical findings from several ethnographic studies. She reports problems between the human operator and the system, and describes how operators have to put in a lot of work to create a working system. She therefore emphasizes the need for a user-centred design approach to the development of new on-board systems (Lützhöft 2004).

The new, highly integrated electronic chart systems seem to have improved the performance and efficiency of navigation, but have perhaps not led to the expected decrease of workload. The reason for this may be found in a less successful development of the human–system interaction environment.

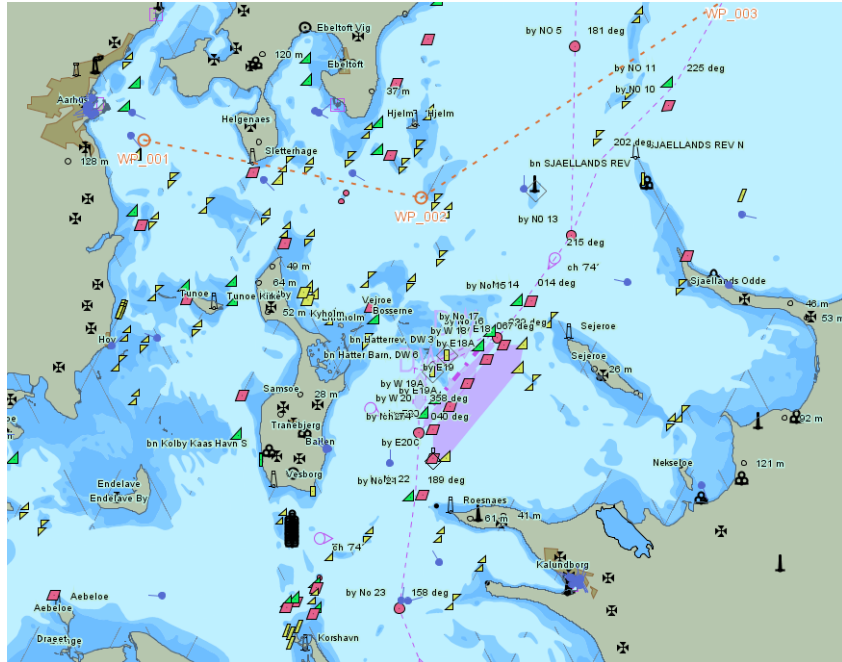
One might also note that while the printed chart has at least 300 years of cartographic design development under its belt, the new electronic medium has still some way to go before achieving the legibility of traditional paper charts – compare Figure 18 with the paper chart in Figure 16.

### **Information design on the bridge tomorrow**

Tomorrow will bring more and bigger ships, and less navigable space due to an ever-growing number of offshore energy and aquaculture installations. The complex traffic environment will be a challenge for tomorrow’s

**Figure 18**

An electronic navigational chart covering the Belt in Denmark. This type of chart still has some way to go before it can automatically generate a view as legible as the traditional paper chart. Compare with the Danish paper chart in Figure 16.



navigators. Clever automation with better information system integration and enhanced user-friendliness will be needed – for as long as humans remain on board.

### E-navigation

In 2006 the International Maritime Organization started the work on a concept called ‘e-navigation’ (IMO 2006). E-navigation is defined as:

the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment. (Kystverket 2014)

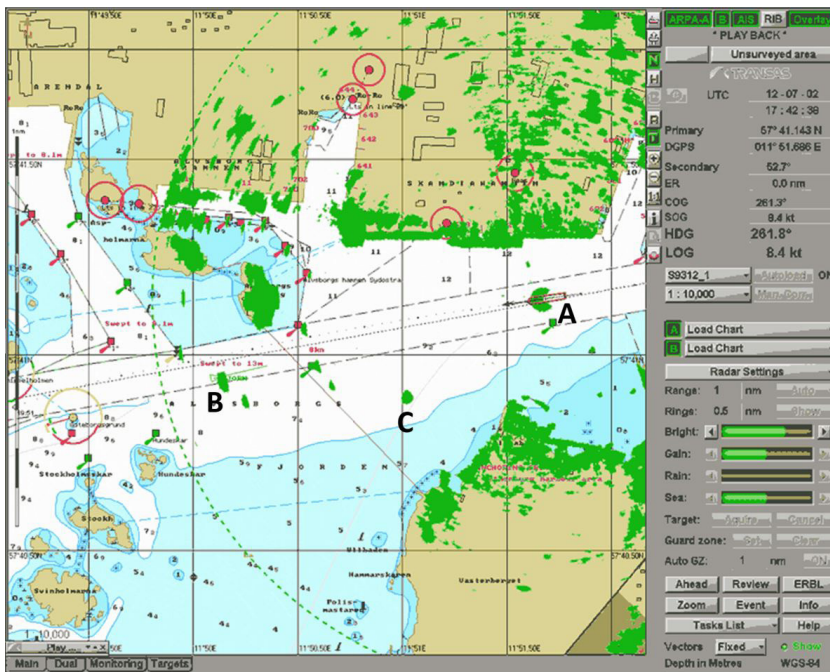
The driving force behind the e-navigation initiative was a concern shared by many stakeholders: That a lack of standards made development of new applications difficult, and that of this reason it is difficult to achieve the potential benefits of system integration. The concerns were about safety and efficiency, and the human navigator who had to deal with a plethora of unintegrated systems. Information necessary to solve real-world problems was already out there, but needed to be made available in a human-friendly way. Some of the misunderstandings leading to accidents could perhaps be avoided by presenting the information more effectively.



### Visualization of intentions: sea traffic management

Initially, the nautical chart served as a repository for static information (slowly changing over time). Dynamic information like the radar image, or the names of ships through the Automatic Identification System (AIS), was shown on separate screens, and then ‘manually’ integrated in the head of the user.

In Figure 19 we can see how the radar information has been integrated with the chart image and that the chart is correctly positioned relative to own ship (A). The radar also confirms the AIS target of an approaching ship (B) and the position of a boat without AIS transponder (C).



**Figure 19**

An ECDIS with radar overlay and AIS integrated. Three screen displays has been integrated into one, allowing the navigator to see all information in its right position. The port of Gothenburg, Sweden.

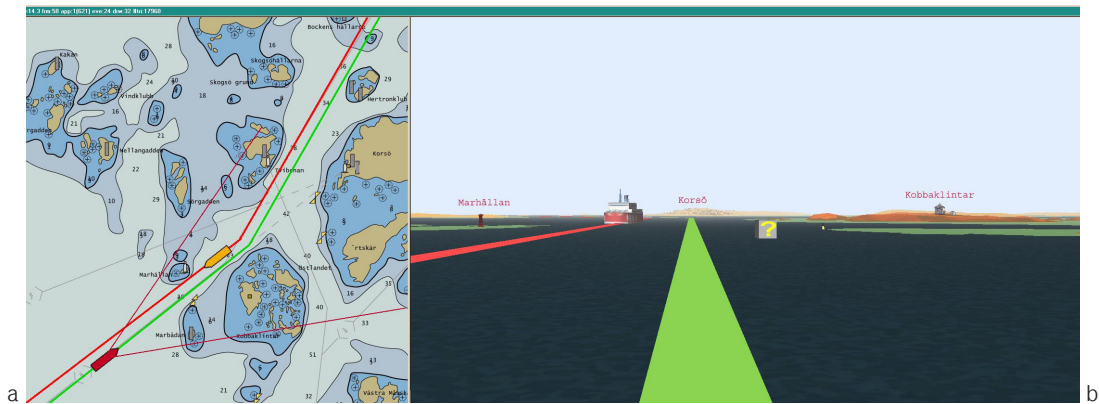
Courtesy Transas AB.

The cost of this integration is higher information density. An untrained observer might call it clutter, but the fact is that it allows the navigator to filter out unimportant information since he sees relevant and important information in its appropriate place.

In Figure 17 we saw an example of an ECDIS where the planned voyage of the own ship was drawn on the map in red. We might say that this course is a visualization of the future position of the vessel. You can also see the predictor, the ghost ship symbol ahead of the real position, which is an extrapolation of the ship's speed and turn-rate 30 seconds into the future. In an attempt to make ship traffic more efficient and safe, several projects are now attempting to communicate information not only of a ship's present position but also its intended course to other ships in the vicinity.

### Cognitive offloading: the egocentric 3D map

Using the bird's-eye perspective of a map for finding your position is not a trivial task, but one that requires training and good spatial ability. First, you have to decide on your own presumed position on the map and imagine how the surrounding terrain would look like from that point. This mental view then has to be compared to the real view to see if it fits. If not, the whole procedure has to be redone. Modern technology can change all this. By creating a 3D model of the map and letting the navigation system position the camera, a dynamic coastal view can be created (see Figure 20).



**Figure 20**

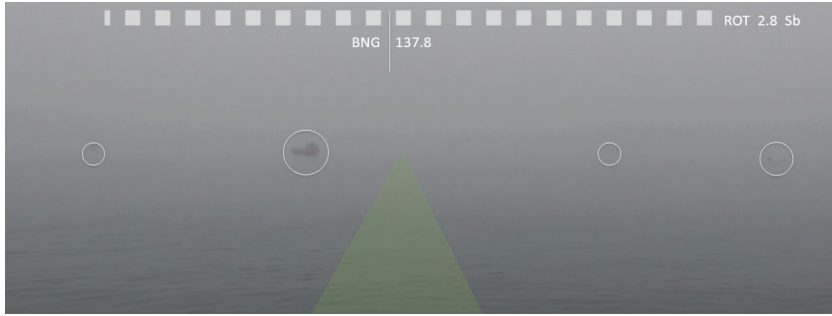
Two map displays.  
a. The traditional exocentric north-up bird's-eye view.  
b. The new egocentric out-of-the-window view.

Screen dump from prototype application.

Laboratory experiments in a maze showed clearly that the egocentric 3D out-of-the-window coastal view provided faster decision making and fewer errors than the traditional exocentric map types. The egocentric 3D map was also ranked as the most user-friendly in experiments done with amateurs and navigators in Sweden, and with navigators in China (Porathe 2006; 2012).

By removing the need for performing mental rotations, the egocentric map display lessens the cognitive workload of the user. A known problem in automation is that the situation awareness of the operator may be reduced when going from manual control to just monitoring (Wickens and Hollands 2000; Endsley 1996).

This in turn leads to what has become known as an out-of-the-loop performance problem. Once something goes wrong, forcing the human to retake control, there is often a lack of situation awareness, and certain types of accident are characterized by the operator's sudden loss of orientation. Valuable time is lost when trying to regain situation awareness – which might lead to a disastrous situation. When vehicles navigate on autopilot and crew members need to retake control, time will be a valuable asset. Thus, a cognitively less demanding display system might save valuable seconds. One might speculate that a transparent head-up display



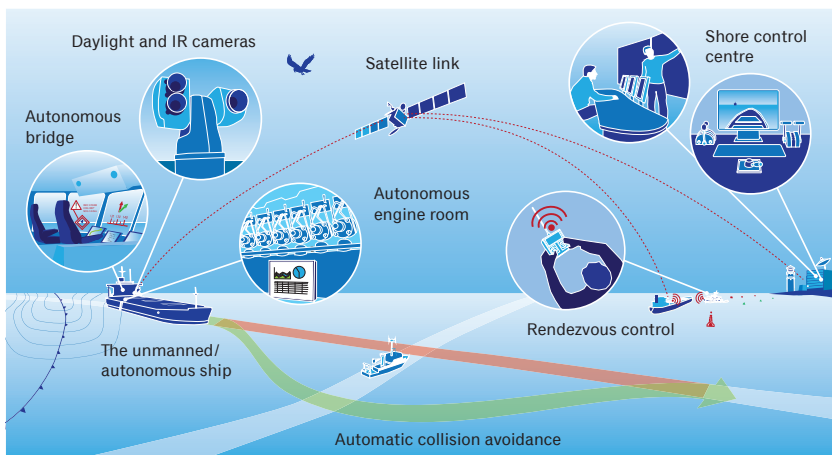
**Figure 21**  
A vessel's own track and the positions of other vessels projected on to the windscreen in a head-up display.

‘superimposed’ on the natural out-of-the-window view will become a common way to display information at sea just as it has been for many years in the air (Figure 21).

### The end of the story of navigation: unmanned ships?

Will ever more advanced integration of information, including knowing the whereabouts and intentions of all ships, lead to unmanned ships? Some think so. In February 2014 Rolls Royce presented a project of unmanned ships, and the author of this chapter has earlier been involved in the EU project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks). Figure 22 shows a concept drawing from the project.

Will unmanned ships also be the end of information design solutions on the ship bridge? If there is no one on the bridge, there is no need to visualize information, because visualization is about making abstract and complex information easily understandable for humans. However, somewhere there will always be someone monitoring the unmanned vessels, and if this place is in a location far away from the actual scene, the need for visualization might be even bigger than on a bridge at sea. Maybe it is in this location the real benefit of 3D nautical charts – creating an immersive virtual presence of the scene at sea – will come.



**Figure 22**  
A concept drawing from the autonomous and unmanned ship project MUNIN.

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